Identifying Imbalances in a Portfolio of Safety Metrics: The Q4-Balance Framework for Economy-Safety Tradeoffs

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Abstract. Despite the desire to utilize proactive safety metrics, research results indicate imbalances can arise between economic performance metrics and safety metrics. Imbalances can arise, first, because there are fewer proactive metrics available relative to the data an organization can compile to build reactive metrics. Research also has shown a number of factors that lead organizations to discount proactive metrics when they conflict with shorter term, more definitive reactive metrics. This paper introduces the Q4-Balance framework to analyze economy-safety trade-offs. Plotting the sets of metrics used by an organization in the four quadrant visualization can be used to identify misalignments, overlap, false diversity as well as to identify complementary and reinforcing metrics that produce a balanced portfolio for an organization.

1 PROACTIVE SAFETY METRICS IN AVIATION

Aviation continues to achieve excellent safety levels. Yet the record of success is punctuated by notable accidents such as Überlingen, Air France 447, and Linate. To maintain and extend the safety record of aviation, the industry would like to use proactive metrics that anticipate and warn of areas of possible increased safety risks and be able to act in advance of incidents and accidents (e.g., European Commission, 2011). This becomes more important as traffic loads increase, as extreme weather events occur more frequently, as new technologies are introduced (e.g., unmanned aircraft, satellite navigation), and as potential system improvements are considered. Proactive safety metrics are an important addition to the set of measures available to manage aviation systems because improvements in aviation often come about in response to specific incidents, failures, or rare accidents.

Today's Air Transport System (ATS) has grown in complexity as it meets increased pressures for efficiency and productivity in a changing technological, environmental, and competitive world while maintaining or improving its record of safety (ACARE, 2012). This increase in complexity requires new metrics that allow ATS to identify when brittleness is increasing and evaluate cost effective sources of resilience (Hollnagel et al., 2006). Reactive safety approaches can look at specific risk factors one or a few at a time. Proactive measures, especially given the increasing complexity of the aviation system, help identify emergent phenomena and multi-factor patterns that can contribute to new risks (Herrera, 2012).

One impediment to anticipate changing or new risks before they lead to serious incidents or accidents is a dearth of valid and practical proactive safety metrics (see Hale, 2009). But another impediment is the tendency for organizations to discount available proactive safety indicators when they come into conflict with short term economic and productivity pressures (Woods, 2006). This was seen most vividly in the events leading up to the Columbia Space Shuttle accident where productivity metrics and pressures took priority over indicators of a change in safety risks, i.e., the energy and location of debris (foam) strikes as well as surprises in the source of debris and phase of flight when these strikes occurred (CAIB, 2003).

2 BALANCING ECONOMY-SAFETY TRADEOFFS: THE Q4 FRAMEWORK

This paper describes a new way forward based on the need to balance reactive indicators with proactive indicators on both safety and economy. The authors have drawn on work on proactive safety metrics and advances toward measures of system resilience to develop the Balancing Economy-Safety Tradeoffs framework. The four quadrants of the Balancing Economy-Safety Tradeoffs framework (or Q4-Balance framework) are shown in Figure 1. The framework allows an organization to map the metrics it uses into the four quadrants. The resulting visualization provides the means to develop and utilize a balanced portfolio of metrics that assesses the state of and interactions across all of the performance dimensions critical to modern aviation systems and organizations.

Q4-Balance framework in Figure 1 depicts relationships between classes of performance metrics. Performance metrics fall into a space defined by 2 dimensions: reactive-proactive (the endpoints on the x axis in Figure 1A); economy-safety (the endpoints on the y axis in Figure 1A). The specific performance metrics or indicators used by a specific organization can be plotted relative to the 2 axes: safety/economy and reactive/ proactive. A set of indicators used by an organization, or a function within an organization or across organizations, to guide decisions can be seen in a pattern formed by the distribution of the indicators over the 2x2 space of performance measurements as shown in Figure 1B (note that the figure at the left side shows indicators for two organizations). The structure of Figure 1 reveals an emergent pattern where metrics can be grouped into 4 classes -- economy-reactive, economy- proactive, safety-reactive, safety-proactive -- shown as the quadrants 1 through 4 respectively.

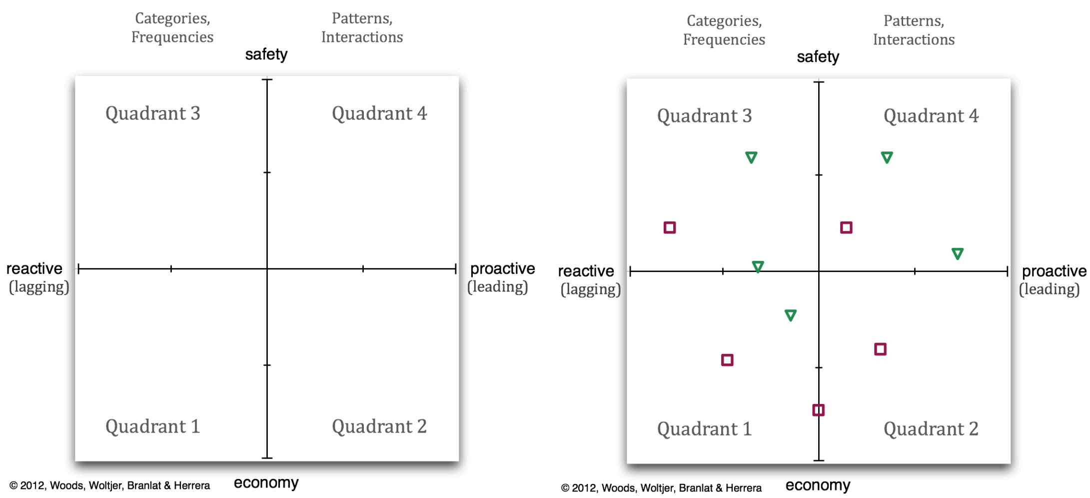
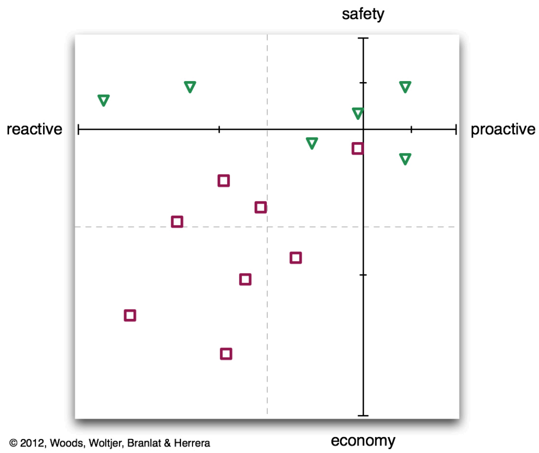


Figure 1. The Q4-Balance framework. Performance metrics fall into a space defined by 2 dimensions: reactive-proactive (x axis); economy-safety (y axis). As a result, metrics are grouped into 4 quadrants (Quadrant 1 = reactive-economic; Quadrant 2 = proactive-economic; Quadrant 3 = reactive-safety; Quadrant 4 = proactive-safety). Figure 1B shows how specific performance metrics used by specific organizations can be plotted as a position in this space to assess the distribution across the quadrants and to look for patterns of imbalance that hinder organizations as they confront trade-offs in risks and uncertainties

The Q4-Balance framework provides the analytic and visual basis to assess balance and imbalance across the four interdependent classes of metrics highlighted in the four quadrant visualization. Imbalances arise when there are fewer proactive metrics relative to reactive ones as shown in Figure 2A. The prevalence of reactive over proactive metrics in a portfolio is shown as shift in the balance point (the 0,0 point in x-y space) so that the left 2 quadrants are larger and the right 2 quadrants have shrunk in size indicating the misbalance in the metrics portfolio. A misbalance can show an organization focusing on reactive metrics while weak on proactive metrics. This will have an impact on the ability to anticipate and cope with future situations. Importantly, research on measures of resilience and brittleness, such as methods to forecast the risk



of loss of resilience, provide a new paradigm for developing valid and useful proactive metrics that apply to both safety and longer term economic viability (business continuity).

Figure 2. Sample Patterns of Imbalance. Some classes of metrics tend to dominate others when there is uncertainty or conflict. Panel A depicts the tendency for reactive metrics (odd quadrants) to get priority over proactive ones (even quadrants). Panel B depicts the tendency for reactive-economy indicators (Quadrant 1) to take precedence over proactive metrics, especially proactive safety indicators, when there is uncertainty, conflict, and differential costs at stake. Note that in both of the cases illustrated in this figure, the indicators that show threats to longer term economic viability also tend to be discounted relative to reactive-economic metrics

Research also has revealed factors that lead organizations to discount proactive metrics when they conflict with shorter term, more definitive reactive metrics (the Columbia accident provides the classic example; see Woods, 2005). Reactive measures tend to be much more tractable and appear more definitive than proactive ones. For example, frequencies can be established from standard databases and reporting systems, and these can be compiled according to different categorization schemes when one is dealing with events that have already occurred (as noted in the column headings in Figure 1). Proactive metrics tend to look for patterns and relationships that can help recognize anomalies early (Klein et al., 2005); these are much harder to compile semiautomatically and they are valuable especially because these indicators have the potential to trigger re-evaluation and re-conceptualization about changing risks before serious incidents or accident occur. Figure 2B depicts this class of imbalance where reactive economic indicators dominate organizational decision making leading to discounting of safety indicators and to discounting of proactive indicators in general. Metrics that capture different aspects of resilience are a particularly valuable means to redress this imbalance, since these were developed specifically in order to assess the risk of this basic pattern (Cook and Woods, 2006).

3 EXAMPLE OF PATTERNS OF IMBALANCE

To illustrate a Q4 application, we use information from the Alaska Airlines Flight 261 accident (NTSB, 2003; Woltjer and Hollnagel, 2007). This case was selected because a large number of human, technological and organizational factors played a role. It also combines inter- and intra-organizational aspects of everyday ATS operations. The accident report determines that excessive wear and lack of lubrication of horizontal trim system jackscrew assembly contributes to the event. The airline extended the lubrication interval and the regulator´s approval of that extension, contributed to increase the likelihood of excessive wear. The design of this component did not include a fail-safe mechanism.

The Q4-balance visualization in Figure 3 is one of a series that was populated through analysis of the accident report, review of potential indicators, changes made based on the accident, and literature review on indicators. Using the accident report, a large list with all possible indicators was prepared. This list was then analyzed, and a subset was selected as important and relevant of indicators to plot into the quadrants. This was done through interdisciplinary and iterative discussions between the analysts. The following was used as guidance to populate the quadrants:

- Q1 economy-reactive, lagging indicators that usually change after the economic pressures change. The lag is typically few quarters or a year. Examples: turn over, operational costs, fuel prices.
- Q2 proactive-economy, leading indicators that usually change before the economy as a whole has changed. These indicators are useful as short-term predictors. Examples: market growth, expected traffic volumes, new aircraft orders.
- Q3 safety-reactive, lagging indicators referring to what has occurred in the past or system states of the past. Examples are technical failures, incidents.
- Q4 proactive-safety, leading indicators referring to aspects that might be critical, what may occur or to possible states of the future. Examples are set of indicators across actors and domains, related to preparedness, interactions, and anticipation of bottlenecks ahead and buffers from resources available to respond to new incidents.

The Q4 framework in Figure 3 shows that the assessment of resilience is not related to single indicator, but is an emergent property given the portfolio and discounting processes that go on when new signals and conflicts arise. Indicators 1 and 2 are required staffing levels for management (decided by the airline) and inspectors (decided by the regulator). The lack of staff effects both production as well as safety. and indicates reactive tendencies. Indicator 3, fleet utilization rate, focuses on economy. Indicator 5 trades economy and safety with different emphasis for the airline and the regulator. Some indicators may be tracked but have little impact on actual investment decisions in safety programs prior to major incidents or accidents. An example is indicator 6 on optimizing maintenance intervals against history and design.

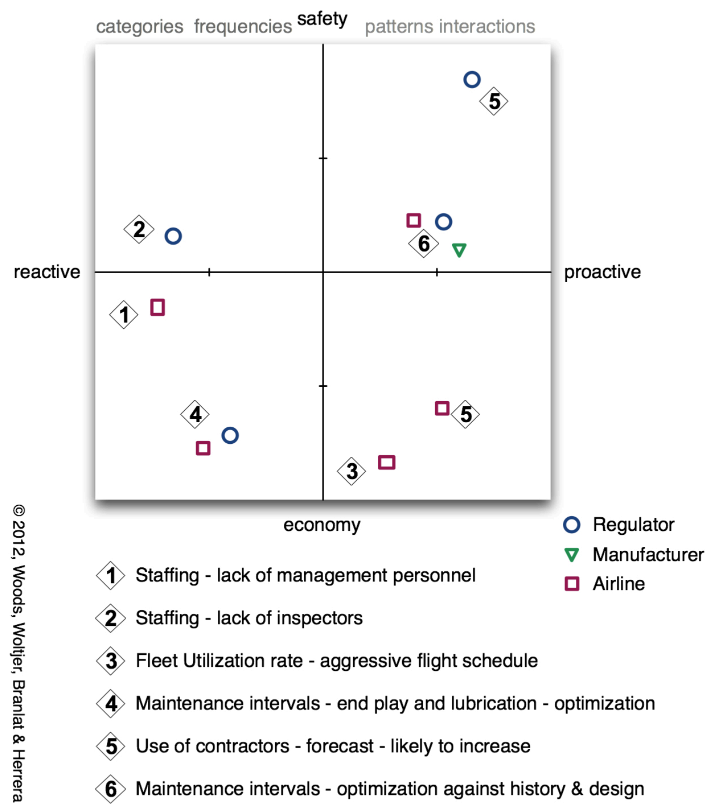


Figure 3. Portfolio of some of the metrics extracted from the case of Alaska Airlines Flight 261 accident (NTSB, 2003).

The example was used to stimulate discussions with representatives from regulators, maintenance personnel, and accident investigation board and safety managers on proactive safety management. The Q4-framework provided a representation that can highlight misalignments in the metrics portfolio and imbalances in discounting when conflicts arise in interactions between safety and economic goals. The visualization helped both operational and management personnel reflect on proactive safety and on how organizations respond when conflicts between metrics are made salient. The participants in the discussions based on the Q4 sample were positive about the potential of Q4-framework to contribute to the development of truly proactive safety processes.

4 IMPLICATIONS AND FUTURE DIRECTIONS

Theoretically for safety science, the Q4-Balance framework provides a new path to model the safety-economy goal conflict. We believe this model can explain paradoxes about safety such as why is it so difficult to make and sustain a business case for safety. Practically for safety management, the Q4-Balance framework provides a visualization to reveal balance or imbalance on a portfolio of performance metrics. The Q4-Balance can be into practice first as a way to describe metrics that are currently used by an organization. It can be used as a part of an assessment of resilience in terms of balance, conflict resolution, and discounting dynamics (as well as metrics in Quadrant 4). Third, it can serve as a critical tool to helping the organization manage its safety investments relative to financial pressures. The visualization of the portfolio helps determine when interventions are needed and which type of interventions (deciding what to do and following through so that these investments produce impacts). When subsets of metrics in the different quadrants align, the overall picture is consistent, despite the uncertainties associated with each specific metric, so that the organization can make investment decisions with confidence. When there is a divergence between reactive and proactive indicators and between safety and economic indicators, organizations can conclude that their ability to balance trade-offs and to assess changing risks has weakened or new risks could arise to threaten organizational performance in the future (Hollnagel, 2011). New analyses are underway in aviation and health care to develop guidance to analysts on how to plot/ position indicators in the quadrants, how to capture discounting, and new ways to populate quadrant 4.

In summary, despite the desire to utilize proactive safety metrics, research results indicate imbalances can arise between economic performance metrics and safety metrics. Research also has shown a number of factors that lead organizations to discount proactive metrics when they conflict with shorter term, more definitive reactive metrics. This paper introduces the Q4-Balance framework to analyze economy-safety trade-offs. Plotting the sets of metrics used by an organization in the four quadrant visualization can be used to identify misalignments, overlap, false diversity as well as to identify complementary and reinforcing metrics that produce a balanced portfolio for an organization. The Q4-Balance framework depicts relationships between classes of performance metrics. Performance metrics fall into a space defined by 2 dimensions: reactive-proactive and economy-safety. The Q4-Balance framework provides the analytic and visual basis to assess balance and imbalance across the four interdependent classes of metrics highlighted in the four quadrant visualization.

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